Post Launch Performance of a Hot Cathode for Electron Ionization of a Space Borne Time-of-Flight Mass Spectrometer (NIM on board JUICE)

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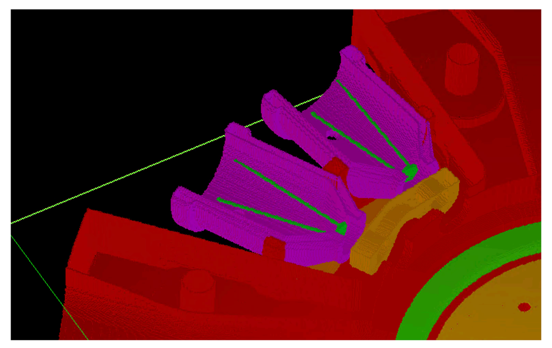
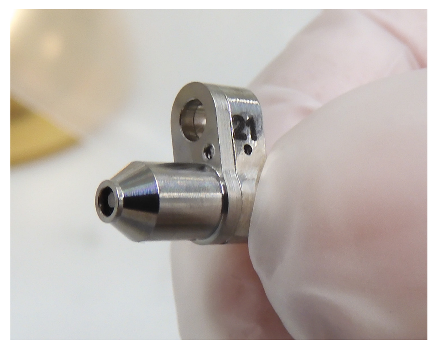
Abstract

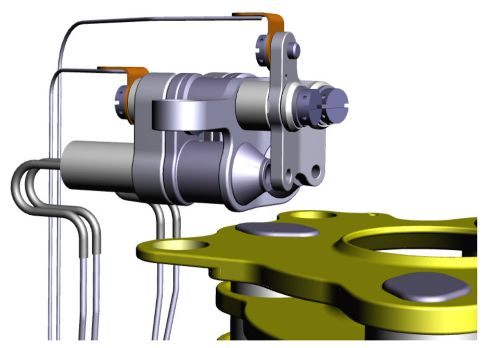
On 14 April 2023, the JUICE spacecraft was launched to the Jovian system to study the emergence of potentially habitable worlds around gas giants. The Neutral-Ion Mass Spectrometer (NIM), developed by the University of Bern, will characterise the atmospheres of the Galilean moons and analyse subsurface material ejected by Europa's plumes. **NIM uses a power-efficient hot cathode filament which creates an electron beam to ionize atoms and molecules for mass spectrometric analysis.**

For this mission, we employ customized yttrium oxide (Y_2O_3) cathodes produced by Kimball Physics, based on the ES-525 design. Given the criticality of correct cathode operation, two cold-redundant cathodes are installed in the NIM instrument.

This study compares the performance of the space-qualified cathodes in the Proto Flight Model (PFM) instrument, post-launch (in orbit and cruise) commissioning, with both expected performance metrics and laboratory-tested cathodes in the Flight Spare (FS) instrument.







Performance

The cathodes operate within a nominal emission range of 100 to 300 µA. Without active beam shaping, power consumption varies between **1.2 and 1.6 W** (up to 1.8 W for the deviating PFM cathode 1) with a current draw of **860 to 980 mA** (up to 1030 mA). Optimal beam shaping increases the current requirement by approximately 20 mA.

The heating current drawn by the cathode is expected to increase over the long term (**up to a lifetime of 10'000 operating hours**) due to degradation of the coating.

Conditioning of Cathodes in Space

When kept clean and maintained under UHV vacuum conditions, yttrium oxide (Y_2O_3) cathodes can be brought into nominal operation mode almost instantaneously. However, following a break — such as after launch — or after thruster firings, they require conditioning. This involves a slow, well-controlled heating process with inactive beam-shaping and bias electrodes, a procedure that may take from one to several hours.

Richardson – Dushman Equation

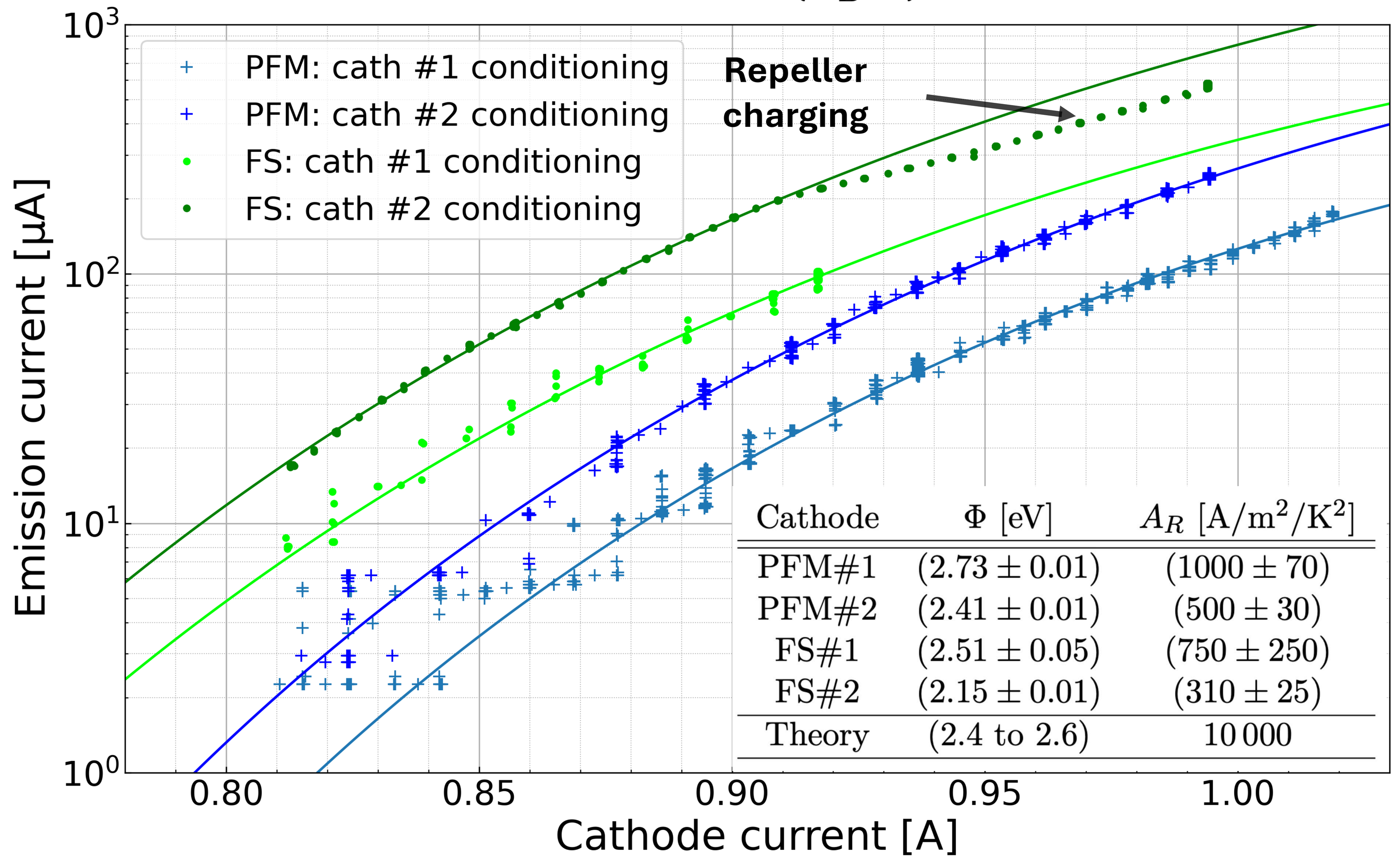
The hot cathode filaments perform in accordance with theoretical expectations (Richardson–Dushman equation), but with lower Richardson constants, both in the laboratory and in space. We assume this deviation arises from differences in characterisation configurations as well as from launch-induced vibrations.

These vibrations might have caused slight bending of the cathode legs, resulting in asymmetry between the emitting disk and the surrounding repeller electrode.

Temperature Inferred from:

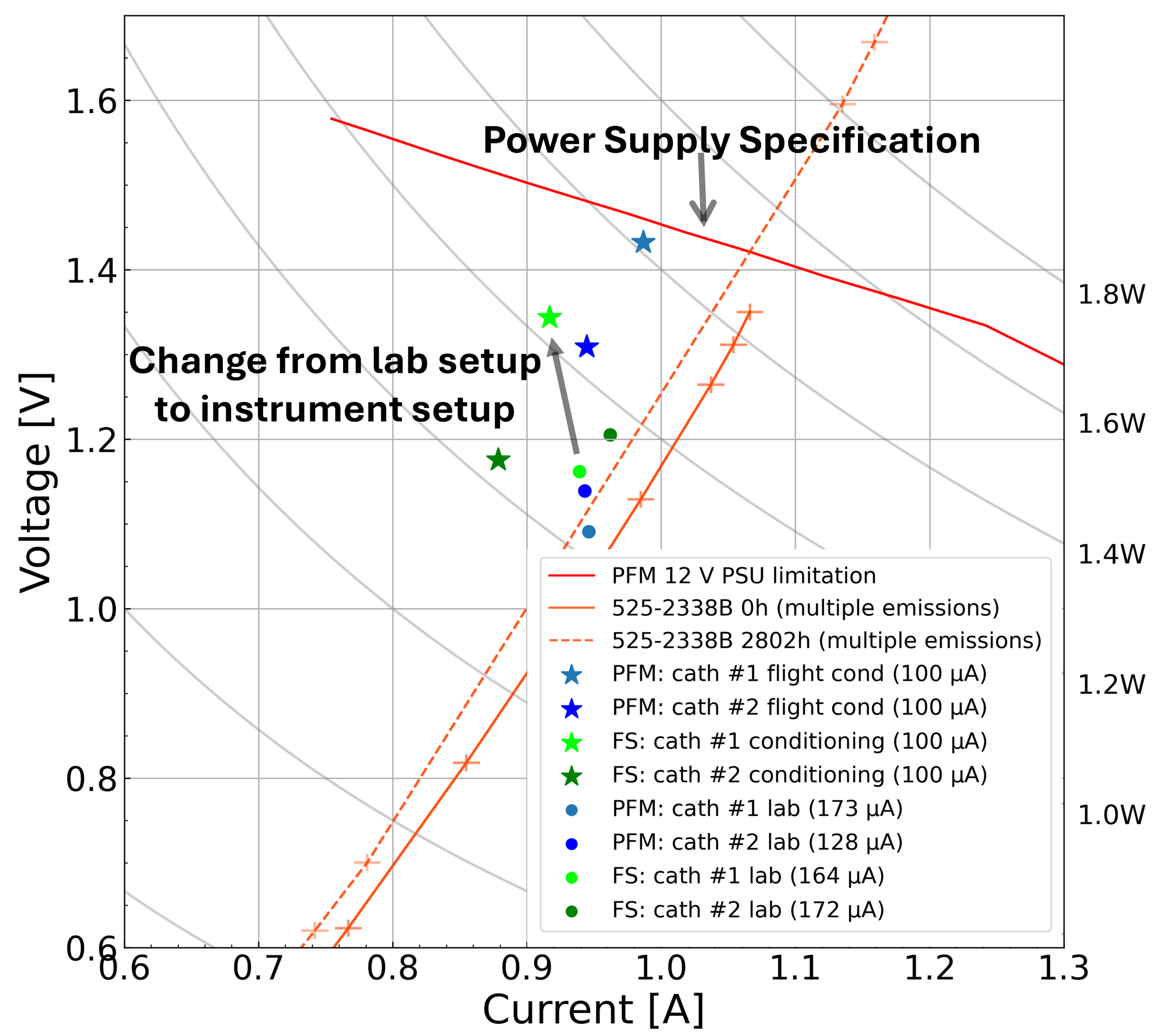
- Heating current
- Supply power
- Cathode charact.

measured $\longrightarrow I_{em} = A_R A_{em} T^2 \exp\left\{\frac{-e\Phi}{k_B T}\right\}$



Cathode	Φ [eV]	A_R [A/m²/K²]
PFM#1	(2.73 ± 0.01)	(1000 ± 70)
PFM#2	(2.41 ± 0.01)	(500 ± 30)
FS#1	(2.51 ± 0.05)	(750 ± 250)
FS#2	(2.15 ± 0.01)	(310 ± 25)
Theory	(2.4 to 2.6)	10 000

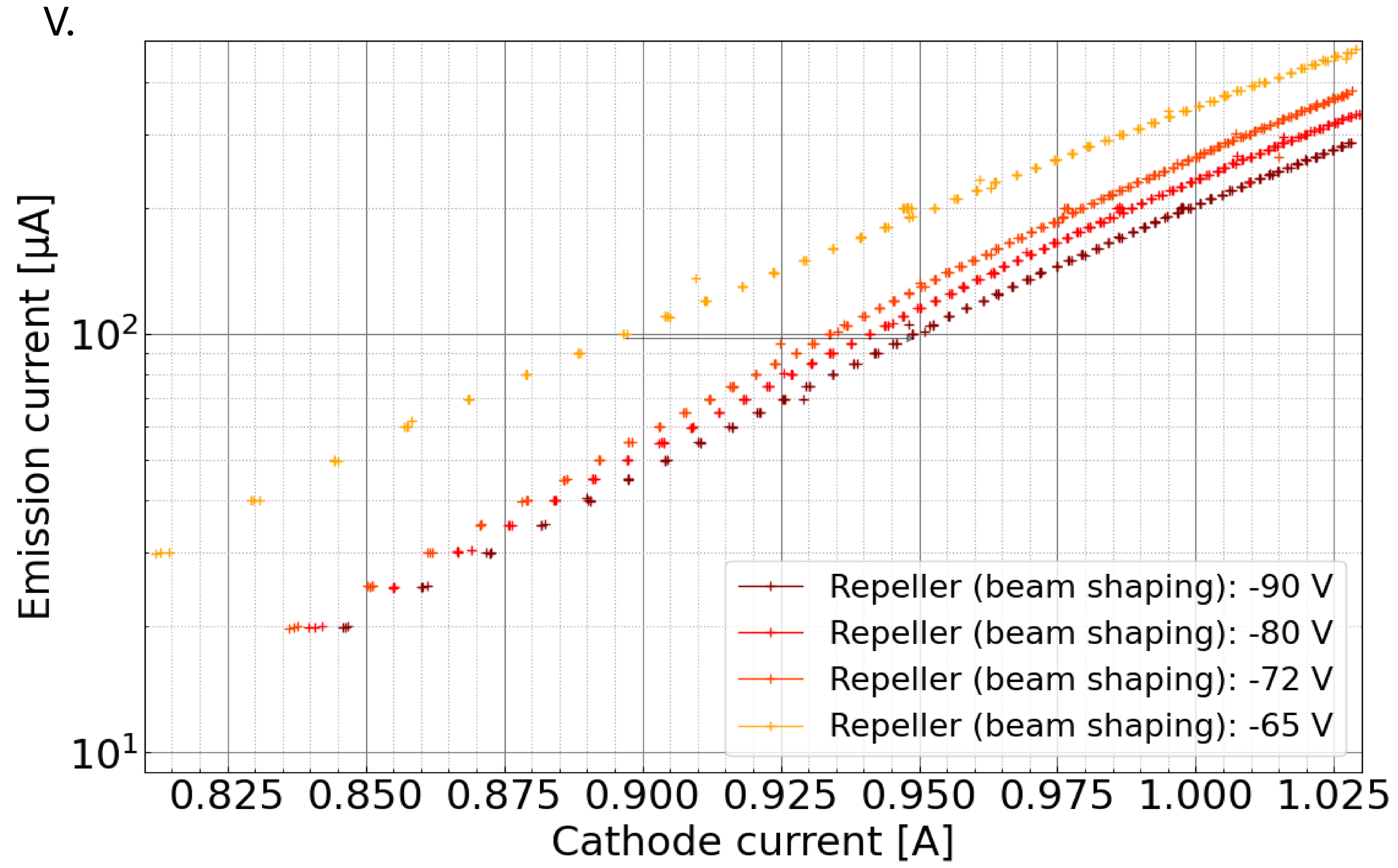
Handling Limited Power Resources



Initiated working-point plot to track the long-term aging and expected power requirements by performing regular characterisations of the hot cathodes. Left shift of a test cathode in the laboratory setup due to aging after 2802 hours.

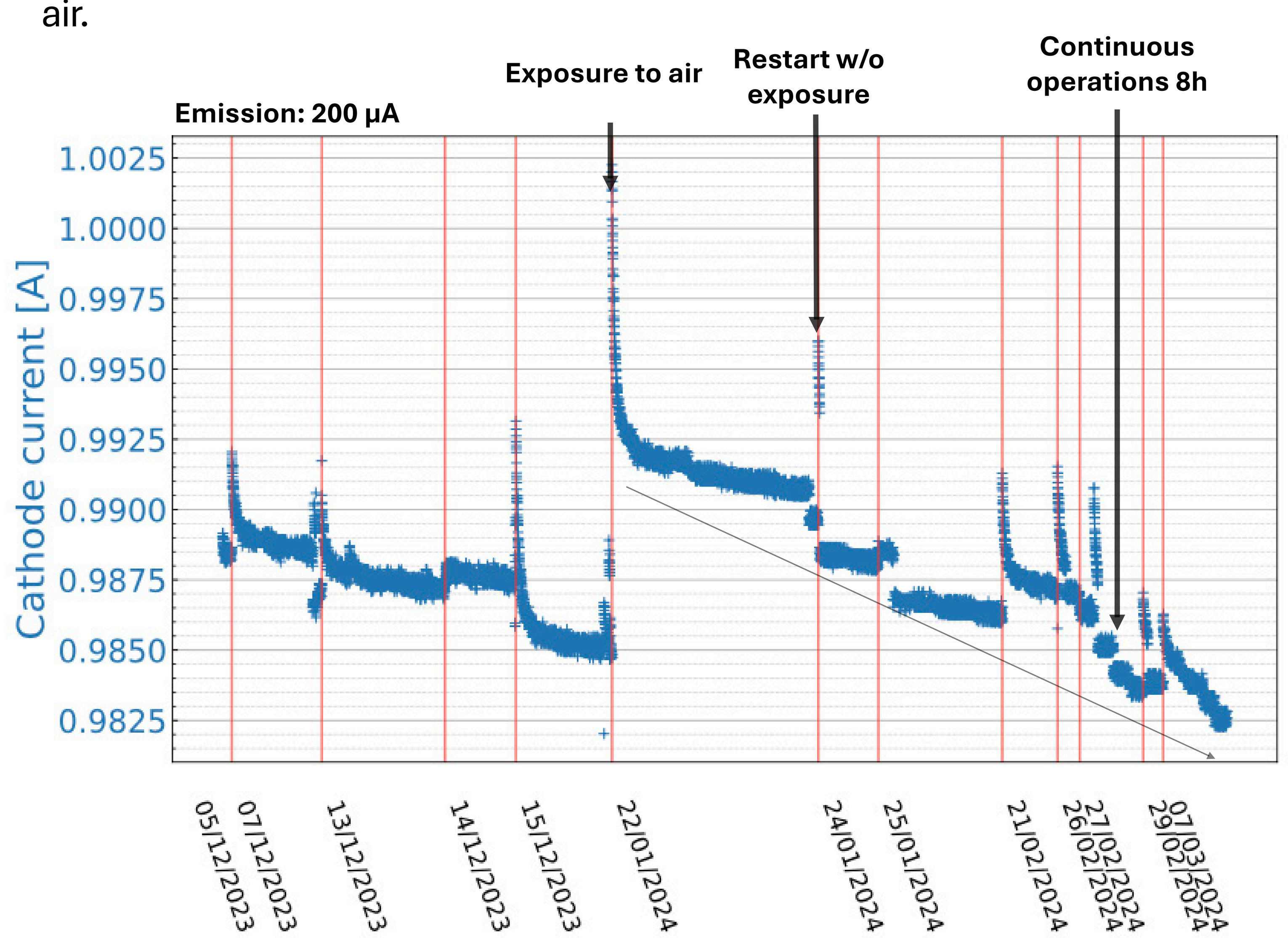
Beam shaping

Electron beam shaping significantly enhances the measurement performance of the Mass spectrometer NIM. However, this optimisation leads to an increase in cathode current for a given level of emission. The optimal value for the electron repeller is **experimentally and numerically** determined to be –98 V, the bias voltage is set to –70 V.



Cathode "burn-in" behaviour

The short-term behaviour, up to 100 hours of operation, reveals a "burn-in" effect: cathodes exhibit improved performance when used under specific active beam-shaping configurations, an effect disrupted after exposure to air.



References

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